

MEASUREMENT OF RAYLEIGH WAVE ATTENUATION IN GRANITE USING LASER ULTRASONICS

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INTRODUCTION

The use of ultrasonic waves to characterize a material requires the measurement of a variety of wave attributes such as phase velocity and attenuation. For example, experimentally measured phase velocities can be used to calculate elastic constants (such as the Lamé constants λ and μ), while attenuation results can be used to characterize the microstructural properties of a material (such as grain size, porosity or microcrack distribution).

This research uses laser ultrasonic techniques to make in-situ measurements of the frequency-dependent Rayleigh wave attenuation in granite. Attenuation analysis (unlike wave velocity measurements) involves the accurate measurement of wave amplitudes as a function of propagation distance. Any inconsistency in the ultrasonic source will result in inconstant wave amplitudes, which will cause errors in the attenuation calculations. This research uses a dual-probe interferometer to ensure that the laser source generates wave amplitudes that are truly constant. The second probe (receiver) enables an independent, quantitative measure of each wave amplitude (as a function of frequency) and provides a normalization value that is used to remove slight variations in source strength.

In order to demonstrate the accuracy of the proposed attenuation measurements, a reference specimen made of aluminum is examined first; these results exhibit the bandwidth, fidelity and robustness of laser ultrasonic measurements that are necessary to make accurate attenuation measurements.

EXPERIMENTAL PROCEDURE

Rayleigh surface waves are generated with a Q-switched Nd:YAG laser, using an ablation generation mechanism. This mechanism generates Rayleigh surface waves, as well as body waves that propagate in a single, broad lobe that are normal to the surface. The Nd:YAG laser used in this study emits a spatially Gaussian profile, with a wavelength of 1064 nm and a pulse duration of 4-6 ns. The beam diameter that strikes the specimen is regulated using a focusing lens that allows for modifications in the spot size from the laser

source. In these experiments, the spot size (source size) is 1 mm in diameter. This is important because the spot size and the beam energy dictate the generation mechanism (thermoelastic or ablation).

Laser detection of Rayleigh waves is accomplished with a dual-probe, heterodyne interferometer that is a modified version of the instrument described in detail elsewhere (Bruttomesso et al.[1]). This optical device uses the Doppler shift to simultaneously measure out-of-plane surface velocity (particle velocity) at two points on the specimen's surface. The interferometer works by measuring frequency changes in the light reflected off the specimen surface. The interferometer makes high fidelity, absolute measurements of surface velocity (particle velocity) over a bandwidth of 10 MHz.

It is important to note that all the specimens examined in this research have polished surfaces. This preparation enables true non-contact detection (there are no artificial surface treatments such as reflective tape) as well as providing a consistent surface for Rayleigh wave propagation. In order to increase the signal-to-noise-ratio (SNR), each waveform presented represents a collection of averages, sometimes as many as 100. This signal averaging procedure works because noise is random and will average out to zero, while the "real" signal is repeatable and is unaffected by averaging.

Measurement of the frequency dependent attenuation is accomplished using the multi-station method. In the multi-station method, one receiver (the normalization probe) is located at a fixed distance, d , from the source, while the second receiver (probe #2) is located at a variable (propagation) distance, r , from the source (see Fig. 1). A Rayleigh surface wave is generated and detected in this position, and then probe #2 is moved a prescribed distance (with a micrometer) away from the source (along a line on the surface of the specimen), and the procedure is repeated. Note that while the position of probe #2 changes, the locations of both the source and the normalization probe remain the same throughout the entire procedure. As a result, the normalization probe ensures that each waveform detected by probe #2 is due to exactly the same source. A measure of source repeatability comes from an examination of the time domain signal measured by the normalization probe. The granite specimen is a rectangular block measuring 200 x 100 x 100 mm thick.

EXPERIMENTAL RESULTS AND DISCUSSION

Figures 2-3 shows typical Rayleigh surface waves in aluminum and granite at three different propagation distances, r . An assessment of these figures indicate the dispersive nature of the granite is evidenced by the change in shape of the Rayleigh surface waves in the upper plot (close propagation distance) when compared to the lower plot (farther propagation distance). This phenomenon is clearly absent in the aluminum specimen.

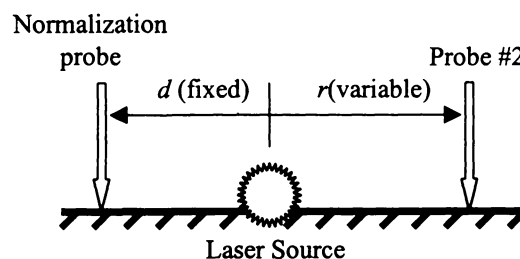


Figure 1 – Schematic of experimental set-up for the multi-station method

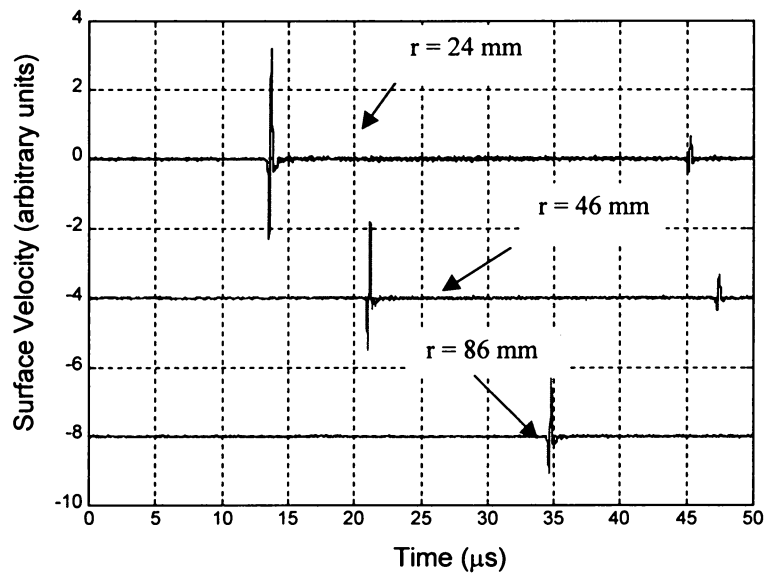


Figure 2 – Typical Rayleigh waveforms measured in aluminum with the multistation method

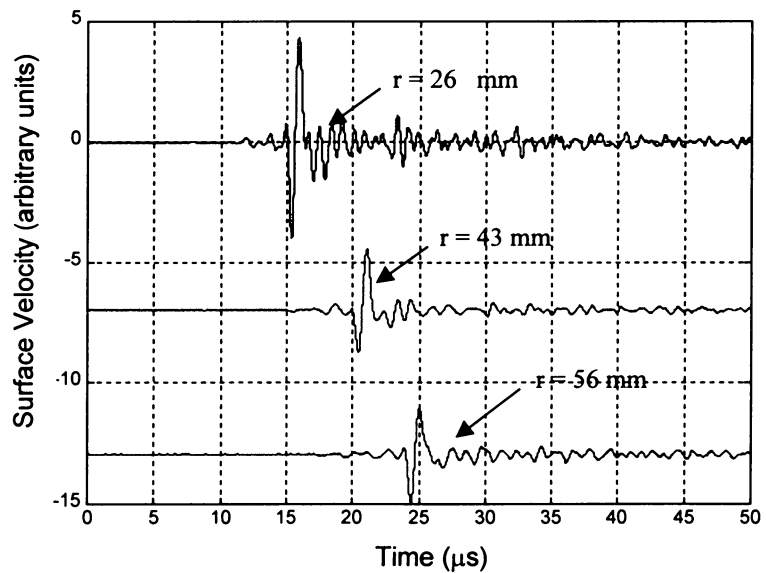


Figure3 – Typical Rayleigh waveforms measured in granite with the multistation method

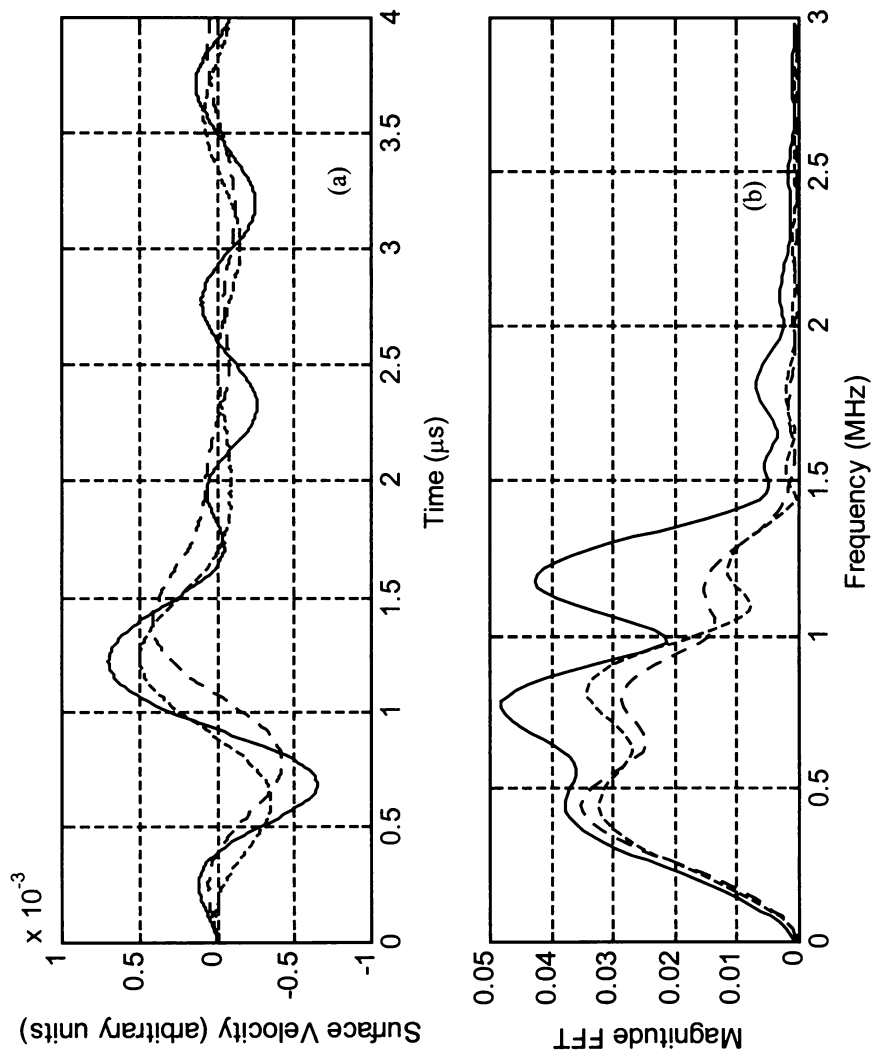
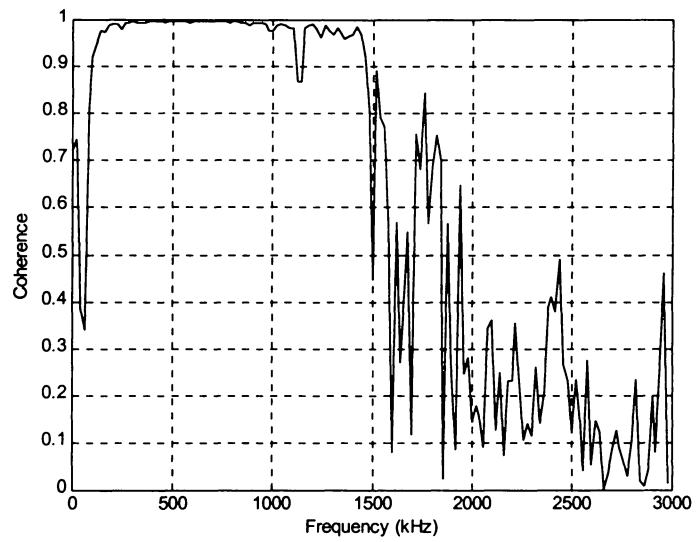
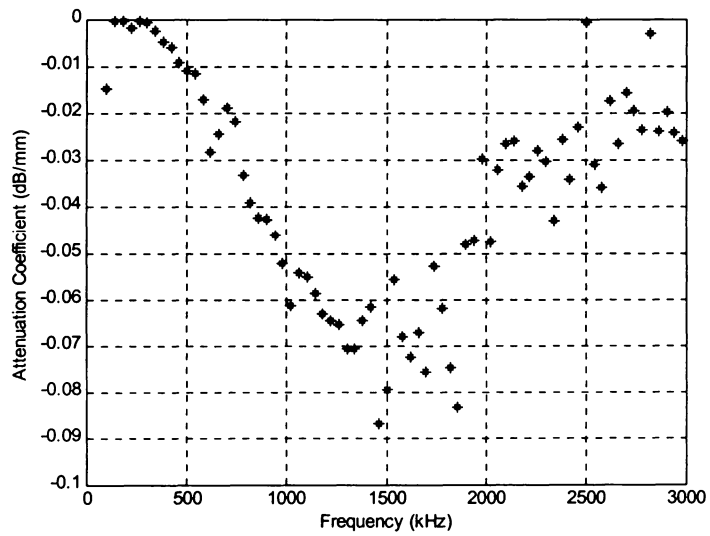


Figure - 4 (a) Typical window for waveforms in Figure 2 (b) FFT's of waveforms in (a)



(a)



(b)

Figure – 5 (a) Coherence and (b) frequency-dependent attenuation in granite

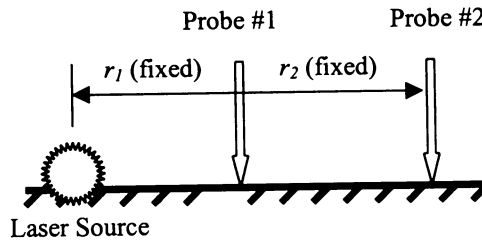


Figure 6 – Schematic of experimental set-up for coherence

A rectangular window is used to isolate the contribution of just the Rayleigh wave portion of the waveform and to track changes in both the time and frequency domains. Figure 4(a) shows the window of three typical waveforms which have propagated three different distances in granite (note here that the waveforms are shifted to remove time delays and corrected for geometric spreading). The frequency of these waveforms is calculated by taking the Fast Fourier Transforms (FFT) of each wave and is depicted in figure 4(b). A qualitative manifestation of the frequency-dependent scattering and absorption losses present in both granite is the fact that the three FFT's in Fig. 4(b) are different from each other; the frequency content of a Rayleigh wave measured in granite is dependent on its propagation distance. These frequency-dependent losses are *quantified* by calculating the frequency-dependent attenuation coefficient, α , using the multi-station method.

In the multi-station method, the frequency-dependent attenuation coefficient (α) is calculated by comparing the geometrically corrected frequency spectrum measured at a number of propagation distances, r_1, r_2, \dots, r_n (probe #2) to that of a reference spectrum (the normalization probe in this study). The resulting α versus f values are shown in Figure 5b. For example, the α measured in granite (and shown in Fig. 5b) is calculated using 15 waveforms (at 2 mm separation intervals) and with forty-eight discrete frequencies, from 100 kHz to 1.5 MHz (at 40 kHz intervals).

An important criteria in determining the accuracy of attenuation measurements is coherence, a frequency-dependent measure of the *linearity* of attenuation measurements. Coherence is defined as the fractional portion of the output signal (the measured Rayleigh surface wave in this case) that is due to the input signal (the laser source in this case) at a specific frequency, f . Coherence is especially helpful in determining the frequency bandwidth through which an experimentally measured attenuation coefficient (α) is reliable. A coherence value of 1 indicates perfect coherence between the input and output signal (100% of the output is due to the input), while a coherence of less than 1 indicates either excessive noise or a non-linear response *at a specific frequency*. Frequency components whose coherence values are less than 0.9 are usually rejected.

The dual-probe interferometer is re-configured (see Figure 6) so that the probes are at two fixed propagation distances (r_1 and r_2) from the laser source. The coherence for granite is shown in Figure 5a. This figure shows that attenuation values above a frequency of 1.4 MHz should be rejected.

CONCLUSION

This research demonstrates the effectiveness of using laser ultrasonic techniques to quantify attenuation losses in heterogeneous materials. By using this state-of-the-art

technology, it is possible to experimentally measure the frequency-dependent material attenuation coefficient, α , over a broad frequency bandwidth. It is critical to note that these experimental measurements are only possible because of the high fidelity, unbiased, broadband, point source/point receiver and non-contact nature of laser ultrasonics.

REFERENCES

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2. Santamarina, J. C., and Fratta, D., *Discrete Signals and Inverse Problems in Civil Engineering*, ASCE Press, New York.